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HEAT PIPE MATERIALS COMPATIBILITY

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1.0 INTRODUCTION and SUMMARY

Ammonia is often the best heat pipe fluid for ambient-temperature spacecraft applications. For the temperature range from -70C to 60C, it has the highest heat-transport capacity except for water, and unlike water, ammonia can be used with the common engineering metals, stainless steel and aluminum. Aluminum is particularly attractive because of its light weight, high thermal conductivity and low cost. In the past, however, it has been the source of considerable aggravation to various practitioners in their attempts to produce heat pipes free of noncondensable gas. For example, gas generation was particularly troublesome in the development of axially grooved heat pipes for the ATS-F satellite [1]. The problem is even more acute when an aluminum tube is used with a stainless-steel wick. At TRW we have been unsuccessful in our attempts to produce completely gas-free heat pipes of this type. In their paper on the subject, Waters and King [2] reported discoloration and pitting of the aluminum tube upon post-test inspection of life-test heat pipes that had generated gas. On the other hand, Kosson et al [3] have produced aluminum-walled heat pipes with stainless-steel tunnel wicks that have at least a sufficiently low level of noncondensable gas to allow the tunnel to prime without trapping a gas-stabilized bubble.

Because of the importance of ammonia heat pipes for spacecraft thermal control, TRW has undertaken this program under contract to NASA Lewis Research Center to experimentally study gas generation. A matrix of thirty-seven 0.61-meter-long, 1.27 cm-diameter heat pipes with metal-fiber slab wicks and internal circumferential grooves were fabricated. These were either aluminum tubes with aluminum wicks, aluminum tubes with stainless-steel wicks, or stainless-steel tubes with stainless-steel wicks. The same experimental approach was taken as in Anderson's study at TRW of nickel/water [4] and stainless-steel/methanol heat pipes [5]. The heat pipes were operated at elevated temperatures of 40, 80, and 100C to accelerate the rate of gas generation and hopefully allow extrapolation of the generation rate to lower operating temperatures. The quantity of gas generation in each heat pipe was calculated from measurements taken monthly for eight months of the temperature profile along the gas-blocked region of the condenser.

These measurements were made with the heat pipes temporarily operating at a low temperature (approximately -20C) to lower the vapor pressure of the ammoni and allow the noncondensable to expand into a larger region. Quantities of gas less than 10^{-8} lb-mole can be detected using this technique.

The primary cleaning procedure used was ultrasonic rinsing in solvents. Six additional heat pipes (fabricated on TRW IR&D funds), were added to the test matrix to test an alternate chemical cleaning procedure as recommended in the Grumman report "Heat Pipe Manufacturing Study". [6]

Analysis of the data from eight months of life tests revealed some unexpected results. For example, there is no clear positive correlation between gas-generation rate and operating temperature. As we anticipated, the heat pipes fabricated from a combination of stainless steel and aluminum generally generated the most gas, the all-aluminum pipes generated a lesser quantity, and the all-stainless-steel pipes generated by far the least. Another unexpected result was that one combination aluminum/stainless-steel heat pipe, which intentionally had the usual vacuum bake-out step deleted from its processing to assess the effect of a small amount of water left in the pipe, generated an order of magnitude less gas than the rest of that type. Another set of two heat pipes that had 0.5% water added with the final charge of ammonia generated the largest quantity of gas for the test matrix. The gas was generated in a short period, and thereafter the generation rate was generally much lower than for the rest of the aluminum-walled heat pipes. These unexpected results, which are analyzed in detail in Section 3.0, cast a new light on the behavior of aluminum and stainless steel with ammonia, and suggest a potential solution to the gas-generation problem.

In many spacecraft applications, the amount of gas generated by aluminum-walled heat pipes will have an insignificant effect on their operation. For example, at TRW we recently developed an aluminum variable-conductance heat pipe as part of a space-radiator system [7]. The required gas loading for the heat pipe is 1×10^{-4} lb-moles, and with the average gas-generation rate measured on the current program fc. that particular type of heat pipe, it would take two-hundred years to generate one-tenth of the original gas loading. In contrast to ammonia heat pipes with aluminum components, the all-stainless-steel heat pipes generated little or no detectable gas.

2.0 EXPERIMENT DESCRIPTION

2.1 HEAT PIPES

The heat pipes used in the study are representative of TRW's current high-capacity non-arterial design. As shown in Figure 2-1, they have a metal-fiber slab wick inside a tube that is circumferentially threaded with 100 threads per inch. The Appendix contains engineering sketches for the heat pipes, their instrumentation and installation. As shown in Figures 2-2 and 2-3, each set of three identical heat pipes is mounted in a common aluminum evaporator block (Engineering Sketch SK74020). Heat is removed from the condenser region by natural convection. To provide efficient hook-up with a 100-channel data acquisition system, each heat pipe is instrumented with 10 chromel-alumel thermocouples (9 spaced at equal intervals along the condenser region and one in the adiabatic region). The thermocouple spacing was obtained by analysis to optimally characterize the anticipated temperature profiles. A bi-metallic thermostat ("Klixon") is used on each evaporator saddle block to provide over-temperature protection. During operation at elevated temperatures all heat pipes are installed in the heat pipe mode, i.e. evaporator elevated. An exception is made for the wickless heat pipes 1-3 which cannot be operated in this mode. During gas measurement all pipes are operated in the reflux mode.

Table 2.1 shows the primary test matrix which consists of all-aluminum heat pipes, all-stainless-steel heat pipes and aluminum-walled heat pipes with stainless steel wicks. For each type, three are operated at 40C, three at 80C and three at 100C. These twenty-seven heat pipes form the basis for assessing the effect of operating temperature on gas generation. In addition, to assess the effect of wick surface area, heat pipes S/N 1-3 have no wick and S/N 13-15 have wicks with a smaller wire diameter. (For a given porosity, the smaller wire diameter gives a higher surface area). To assess the necessity of vacuum bake-out to remove water from the walls during processing, S/N 18-19 had the bake-out steps deleted and S/N 20-21 had 0.5% water intentionally added to the final ammonia charge of 17.5 g.

Figure 2-1. Photograph of the Cross Section of a 1.27-CM-O.D.Heat Pipe With a Metal-Fiber Slab Wick

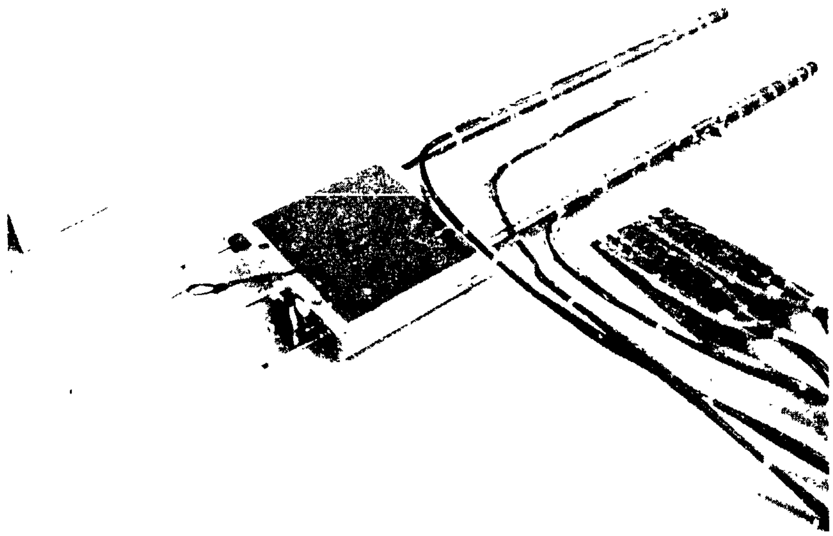

Figure 2-2. Three Heat Pipes in Common Evaporator Block With Instrumentation

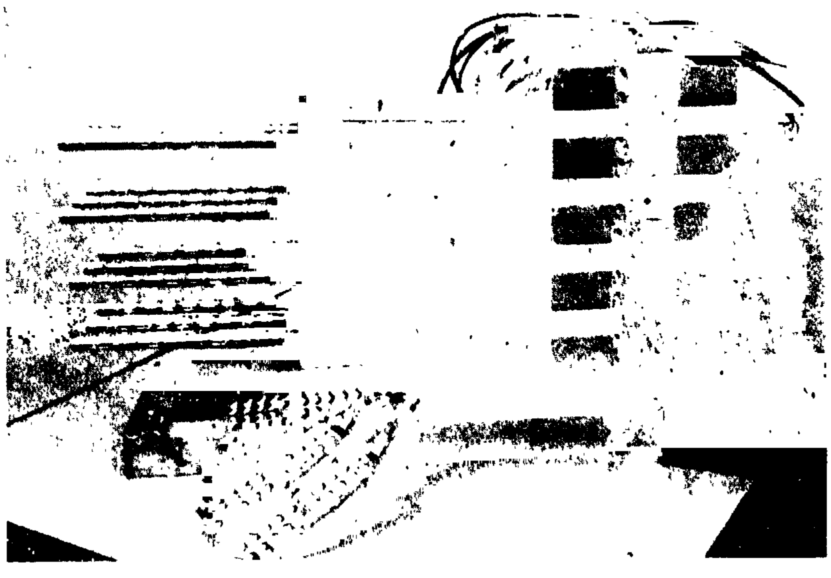

Figure 2-3. Four Sets of Three Heat Pipes in Mounting Rack

TABLE 2.1. Primary Text Matrix

HEAT PIPE SERIAL NO.	TUBE MATERIAL	WICK PROPERTIES MATERIAL	WIRE DIA. (IN.)	POROSITY(1)	TEST TEMP (°C)	REMARKS (2)
1-3	6061-T6 ALUMINUM	NONE	-	-	80	
4-6		304 STAINLESS STEEL	0.0044	81.1	40	
7-9					80	
10-12					100	
13-15			0.0034	81.2	80	Higher wick area.
18-19			0.0044	81.1	80	No bake out.
20-21					80	1/2% water added to Ammonia.
22-24		5056 ALUMINUM	0.0050	82.7	40	
25-27					80	
28-30					100	
31-33	304 STAINLESS STEEL	304 STAINLESS STEEL	0.0044	81.1	40	
34-36					80	
37-39					100	

(1)Measured prior to installation in tubes.

(2)All components cleaned per PR 2-28-1.

2.2 PRETEST ANALYSIS

To minimize the effect of variations in material composition on the gas-generation rate, all similar parts were manufactured from tube or bar stock of the same heat number and all similar wicks from the same spool of wire. All ammonia was from the same container and was certified at 99.998 percent purity (minimum).

Pre-test analyses were completed on the fabrication materials selected for this program. Photomicrographs of polished and etched specimens were taken with an optical microscope at magnifications up to 500X and compared with handbook microstructures. A lot of selected 304 stainless-steel tubing was eliminated after metallurgical examination revealed the tubing was not seamless. Samples of the aluminum and stainless-steel were also examined with a scanning electron microscope at magnifications up to 10,000X to aid in the interpretation of the optical micrographs. All materials compared favorably with handbook microstructures. In addition, samples of the materials used in fabrication were subject to chemical analysis, which confirmed that the materials all conformed to handbook specifications.

Analysis of the ammonia by an independent laboratory showed that in the liquid state all contaminants (H_2, H_2O, N_2, O_2, A, CO_2) were less than 10 ppm, which is the limit of detection for the analysis. In the gaseous state, 1.9 ppm of hydrogen and 0.1 ppm of nitrogen were detected. The rest of the contaminants were below the limit of detection, which, for the gaseous state, is 10 ppm for water and carbon dioxide and 0.1 ppm for oxygen and argon.

2.3 FABRICATION, PROCESS AND FILL

The fabrication and processing of the heat pipes are described in the manufacturing flow charts and the processing specifications in the Appendix. The cleaning procedure PR2-28-1 (summarized in Table 2.2) is a series of ultrasonic solvent rinses. This was TRW's standard heat pipe cleaning procedure at the time the heat pipes were fabricated.

Subsequently, a chemical cleaning procedure (CRP7-12 for stainless steel and CRP7-10 for aluminum, in the appendix) was prepared as recommended in [6] for evaluation in this program. On TRW IR&D funds, four chemically-cleaned heat pipes (two all aluminum (S/N 148-149) and two all stainless steel (S/N 150-151) were added to the test matrix. To assess the necessity for vacuum firing of solvent-cleaned heat pipes, two additional stainless-steel pipes (S/N 152-153) were added that were solvent cleaned but not vacuum fired. These additional heat pipes are summarized in Table 2.3. They were put on test three months after the program-fabricated samples were put on test.

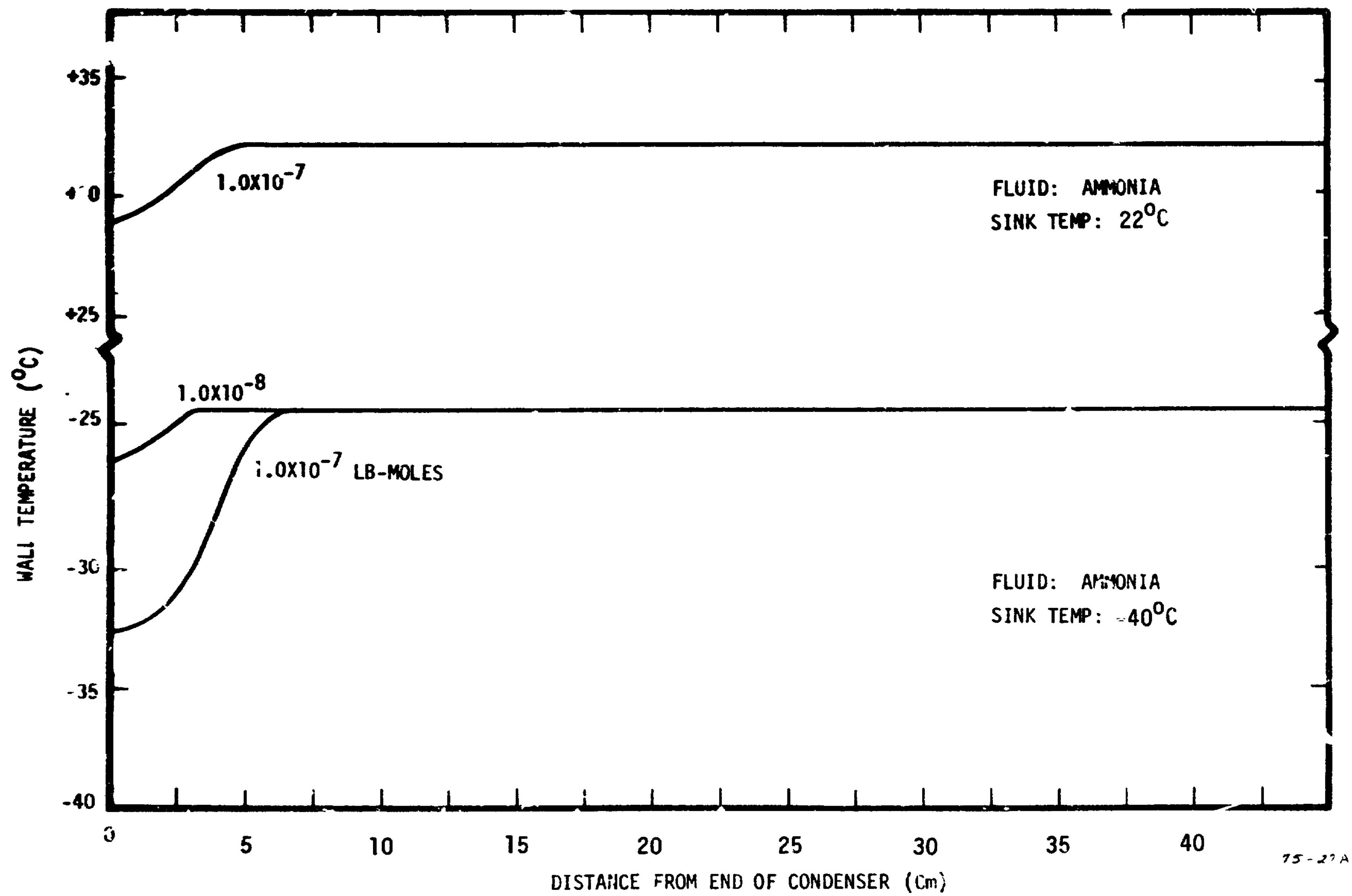

Figure 2.4 Calculated Temperature Profiles in Stainless Steel Heat Pipes.

PR2-28-1

USE FILTERED SOLVENTS
PR13-6-1

ULTRASONIC CLEAN IN FREON TF,
MINIMUM OF 15 MINUTES

DRY IN VACUUM OVEN AT 212 $\pm$ 20°F
FOR MINIMUM OF 5 MINUTES

ULTRSONIC CLEAN IN ACETONE,
MINIMUM OF 15 MINUTES

DRY IN VACUUM OVEN AT 212 $\pm$ 20°F
FOR MINIMUM OF 5 MINUTES

ULTRASONIC CLEAN IN HEXANE,
MINIMUM OF 15 MINUTES

DRY IN VACUUM OVEN AT 212 $\pm$ 20°F
FOR MINIMUM OF 5 MINUTES

STORE IN SUITABLE CONTAINER

Table 2.2. Assembly Cleaning Procedure

Table 2.3. IR&D Test Matrix

HEAT PIPE S/N	TUBE MATERIAL	WICK MATERIAL	CLEANING PROCESS (Spec. No.)
148	6061-T6 Aluminum	5056 Aluminum	Chemical (CRP 7-10)
149	6061-T6 Aluminum	5056 Aluminum	Chemical (CRP 7-10)
150	304 SS	304 SS	Chemical (not vacuum fired) (CRP 7-12)
151	304 SS	304 SS	Chemical (not vacuum fired) (CRP 7-12)
152	304 SS	304 SS	Solvent (not vacuum fired) (PR 2-28-1)
153	304 SS	304 SS	Solvent (not vacuum fired) (PR 2-28-1)

2.4 TESTING

Except when the temperature profiles are measured at low temperatures, the heat pipes are run continuously at their respective operating temperature (see Tables 2.1 and 2.3). Periodically the heat input to the heater blocks · adjusted to maintain the required temperature.

As noncondensable gas is evolved during operation of a heat pipe, it is carried to the condenser end causing a blockage. The quantity of noncondensable gas is calculated from the temperature profile of the gas-blocked region. The profile is measured with the heat pipe operating in a -40C environment, which is provided by a freezer. By lowering the vapor temperature, and hence its pressure, the noncondensable gas expands to fill a larger volume, and thus it results in a larger temperature profile. This is illustrated in Figure 2-4, where the GASPIPE II computer program was used to generate two temperature profiles for the same amount of gas (1.0×10^{-7} lb-moles), but different operating temperatures.

For calculation of the quantity of gas, the condenser region is divided into N intervals, and the temperature at the center of the ith interval is denoted T_i. The number of moles n of noncondensable gas is given by the ideal gas law as

$$n = \frac{\Delta V}{R} \sum_{i=1}^{N} \frac{P_{gi}}{T_i} ,$$

where V is the volume of each interval available for gas and vapor and R is the universal gas constant. The partial pressure of gas, P_{gi} , is the difference between the total pressure given by the vapor pressure P_{va} of ammonia in the adiabatic section and the partial pressure P_{vi} of vapor in the ith interval. A computer program is used to calculate the quantity of gas directly from the wall-temperature measurements.

The measured temperature profiles and calculated gas are shown in Figure 2-5 and 2-6 for the particular heat pipe S/N 25, which is all aluminum and is operated at 80C. This data is typical in that the initial gas-generation rate is relatively high, and after a month it levels out.

Table 2.4 Mean Values for Gas-Generation Rates and Quantity of Gas Generated

Heat Pipe Ser. No.	Tube Material	Wick Properties Material	Wick Properties Wire Dia.	Wick Properties Por.	Op. Temp.	Avg. Gen. Rate	Avg. Gas at End of Test	Remarks
						lb-mole/da	lb-mole	
1-3	6061-T6 Aluminum	None			80C	3.30×10^{-10}	1.92×10^{-7}	No wick.
4-6		304 S.S.	0.0044 in.	81.1	40C	3.63×10^{-10}	2.34×10^{-7}	
7-9					80C	2.74×10^{-10}	2.30×10^{-7}	
10-12					100C	1.96×10^{-10}	2.16×10^{-7}	
13-15			0.0034 in.	81.2	80C	2.40×10^{-10}	1.71×10^{-7}	Higher wick area.
18			0.0044 in.	81.1	80C	4.29×10^{-10}	2.80×10^{-7}	No bakeout.
19						2.20×10^{-11}	2.02×10^{-8}	
20-21					80C	1.14×10^{-10}	6.86×10^{-7}	0.5% water added.
22-24		5056 Al	0.0050 in.	82.7	40C	1.31×10^{-10}	6.71×10^{-8}	
25-27					80C	5.14×10^{-10}	2.06×10^{-7}	
28-30					100C	3.47×10^{-10}	1.55×10^{-7}	
31-33	304 S.S.	304 S.S.	0.0044 in.	81.1	40C	3.37×10^{-13}	2.78×10^{-9}	
34-36					80C	4.11×10^{-11}	8.12×10^{-9}	
37-39					100C	3.46×10^{-11}	1.60×10^{-8}	
148-149	6061-T6 Aluminum	5056 Aluminum	0.0050 in.	82.7	80C	3.01×10^{-10}	8.93×10^{-8}	Chem. cleaning.
150-151	304 S.S.	304 S.S.	0.0044 in.	81.1	80C	6.43×10^{-11}	1.54×10^{-8}	Chem., no vac. fire.
152-153	304 S.S.	304 S.S.	0.0044 in.	81.1	80C	6.68×10^{-11}	2.15×10^{-8}	Solvent, no vac. fire.

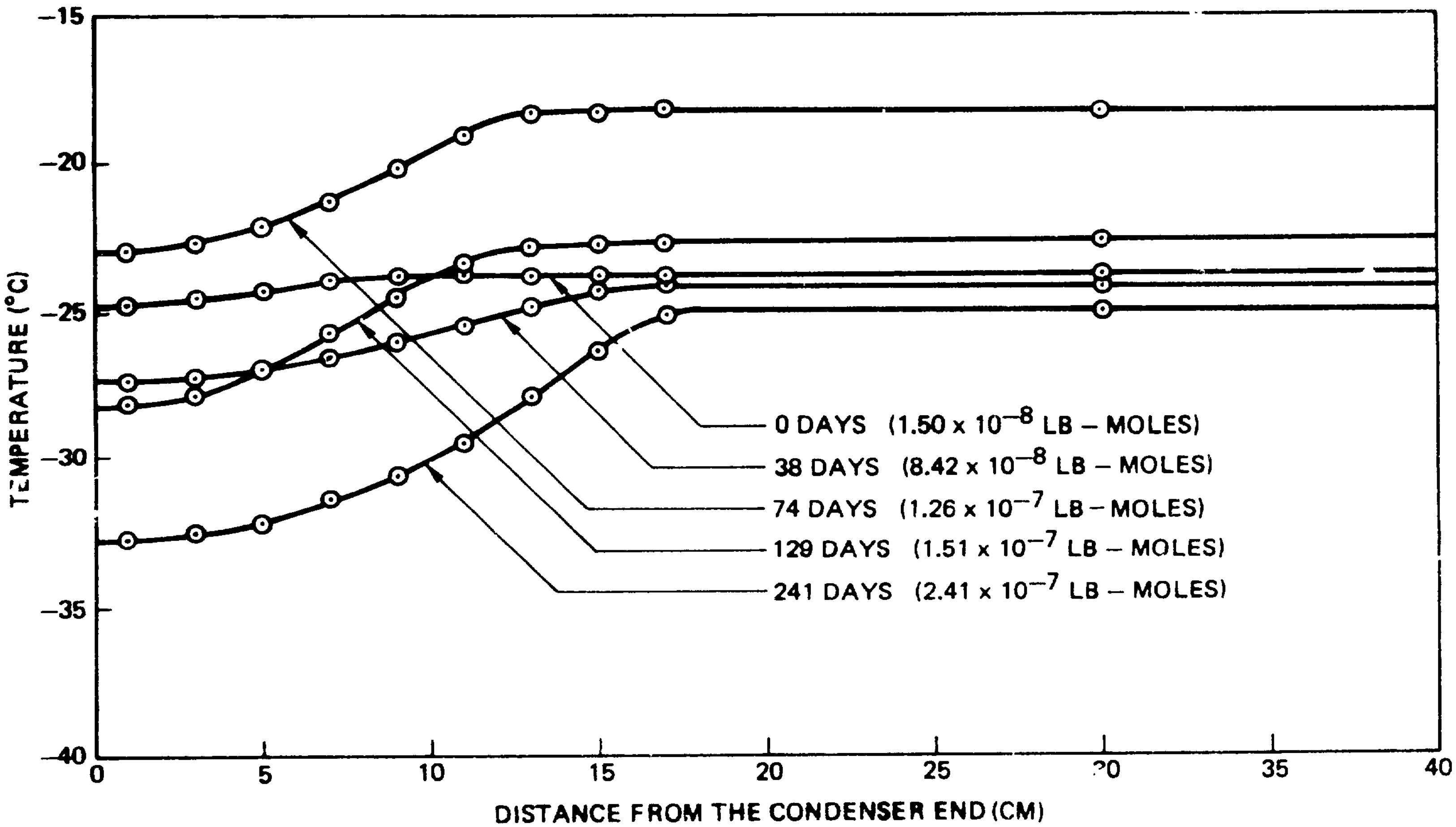

Figure 2-5 Measured Temperature Profiles for All-Aluminum Heat Pipe S/N 25

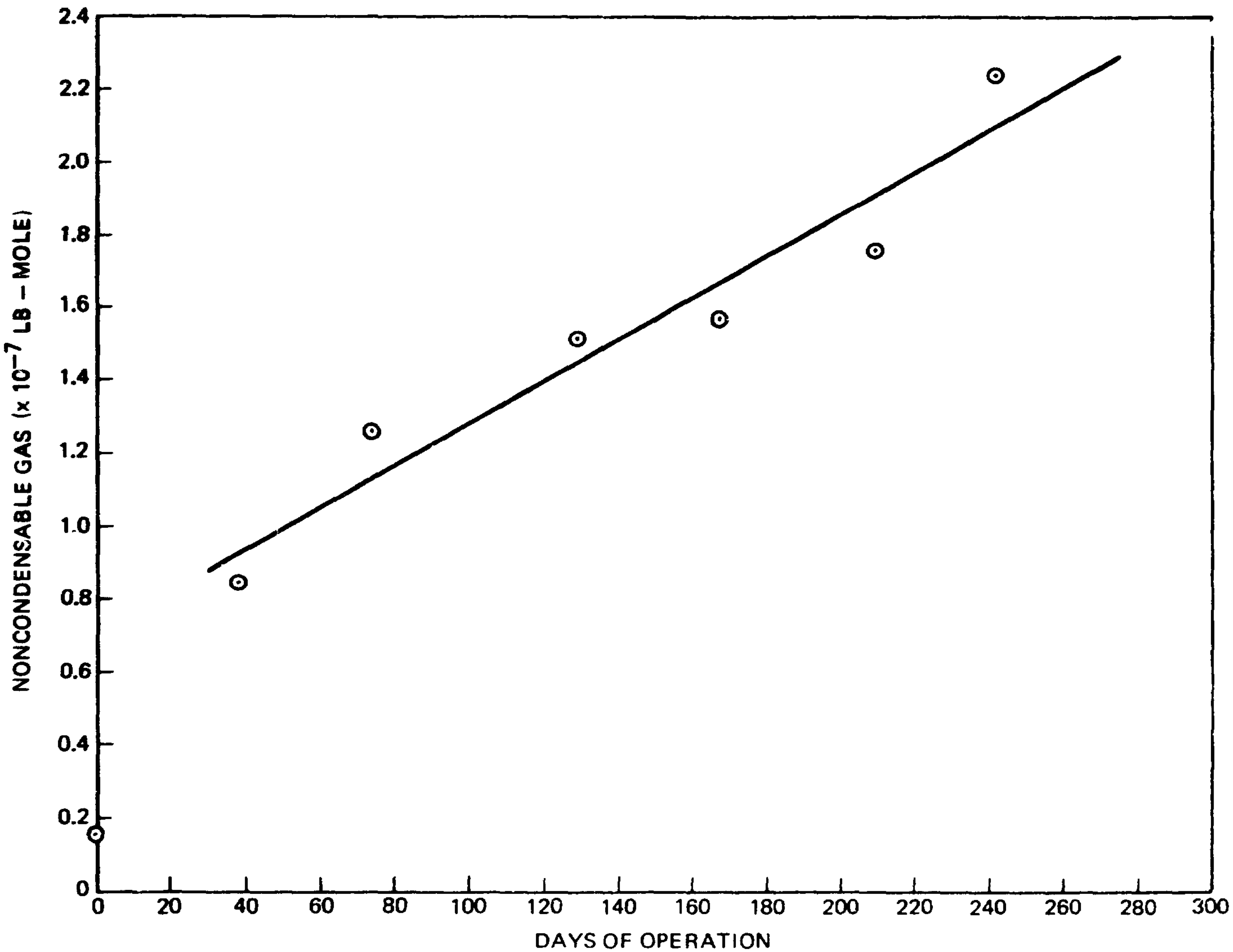

Figure 2-6 Evolution of Gas for the All-Aluminum Heat Pipe S/N 25

An overall gas generation rate of 5.8×10^{-10} lb_m/day was calculated by a least-squares fit of a straight line to the data of Figure 2-6 past 30 days. The data for all of the heat pipes are summarized in Table 2.4. Detailed data for each pipe at each measurement interval is presented in Table A-1 in the Appendix.

2.5 POST-TEST ANALYSIS

Post-test analyses were performed on one of each type heat pipe tested: Al/SS wick (S/N 8), Al/Al wick (S/N 27), and SS/SS wick (S/N 39). Heat pipe S/N 12 was also analyzed to determine the source of a leak which caused the pipe to fail in test.

Mass spectrometry gas analyses were performed on ammonia samples from heat pipes S/N 8 and S/N 27 to determine the noncondensable gas or gases generated during testing. Valves were attached to the two pipes to allow easy removal of the gas samples. This was done by placing the fill tubes in a glove box filled with helium, and then chilling the heat pipes in liquid nitrogen to 77°K. The fill tubes were cut off with a tubing cutter and valves attached. The total time for attaching each valve was approximately one minute.

Gas and liquid samples taken from pipes 8 and 27 were analyzed by an independent testing laboratory (data sheet in Appendix). The results show that hydrogen, as expected, is the noncondensable gas and that all other impurities are below 10 ppm except nitrogen. The nitrogen was apparently introduced into the heat pipes during the valve installation.

All four heat pipes were subsequently emptied of ammonia, opened, and visually inspected for internal surface damage. Opening was done by cutting off the end caps, removing the wicks, and cutting the pipes axially into two sections. The cuts were made on a band saw. The internal surfaces of the heat pipes were visually inspected under a microscope.

The only heat pipe with any significant change to the internal surface was S/N 8 (Al/SS wick), where corrosion and pitting occurred the entire length of the heat pipe. Damage was about equal in all sections of the heat pipe. A solid white precipitate, probably Al OH, was deposited in various spots in the evaporator, adiabatic, and condenser sections. Heat pipe S/N 27, (Al/Al wick) and heat pipe, S/N 39, (SS/SS wick) had very little pitting or corrosion, and overall the internal surface looked very clean. Heat pipe S/N 12 was found to be leaking from a circumferential crack approximately 1mm long at the adiabatic end of the evaporator.

3.0 DATA ANALYSIS

3.1 THE EFFECT OF OPERATING TEMPERATURE ON GAS GENERATION

We had expected, based on previous studies with nickel/water [4] and stainless-steel/methanol [5] heat pipes, that the gas generation would be strongly and positively correlated with operating temperature. From Table 2.4 we see that this is not necessarily the case. For the three sets of aluminum-walled heat pipes with stainless-steel wicks that were operated at 40C (S/N 4-6), 80C (S/N 7-9), and 100C (S/N 10-12), the trend is exactly opposite. At the end of the test period they all have generated approximately the same amount of gas; however, the gas-generation rate was lowest for the 100C operating temperature and highest for 40C.

The all-aluminum and all-stainless steel heat pipes, on the other hand, did have their lowest gas generation rate at 40C (S/N 22-24 and S/N 31-33); however, in both cases the 80C pipes (S/N 25-27 and S/N 34-36) generated gas at a higher rate than the 100C pipes (S/N 28-30 and S/N 37-39). The gas generation in the all-stainless-steel pipes was generally so low, however, it was at the detection limit and, therefore, differences in the rates for the all-stainless-steel pipes are not significant.

The inconsistency of the correlation between gas-generation rates and temperature suggests that two opposing processes are occurring. One clearly is the chemical reaction that generates the gas, which is certain to be positively correlated with temperature. The second is passivation of the metal surfaces with a film of corrosion products. Evidently passivation can proceed more effectively or to a greater extent at higher operating temperatures and thus explains the lower generation rates at 100C than at 80C (also lower rates at 80C than 40C for the aluminum/stainless-steel heat pipes).

3.2 THE EFFECT OF THE PRESENCE OF WATER

More unexpected results were found in the data from those heat pipes used to study the effect of the presence of water. Heat pipes S/N 20-21, for example, had 1/2% water added with the final charge of ammonia. Although these pipes generated by far the most gas by the end of the test than any of the others, the gas generation occurred primarily in the first month of operation. Thereafter, these pipes had a lower average gas-generation rate than any of the other aluminum-walled pipes.

The vacuum-bake-out step is used in the processing of the aluminum-walled heat pipes primarily to drive off water. To assess the effect of this amount of water, heat pipes S/N 18-19 did not have a bake-out. Heat pipe S/N 18 performed roughly the same as the pipes that had the bake-out step, except for a slightly higher gas-generation rate. Heat pipe S/N 19, however, produced surprising results: the quantity of gas it generated and the generation rate are roughly a factor of ten less than the rest of the aluminum-walled heat pipes.

The evidence from both the heat pipes without the bake-out step and with water intentionally added points toward water playing a key role in effective passivation of the aluminum. In the case of S/N 19, we can conjecture that without the bake-out there was sufficient water for effective passivation during the high-temperature refluxes. The gas generated during this passivation is purged before the final charge. Heat pipe S/N 18 may not have had sufficient water for the passivation. In the case of S/N 20-21, the passivation occurs during operation with the final charge, and hence the gas generated during passivation remained in the pipes during the life test.

3.3 THE EFFECT OF WICK SURFACE AREA ON GAS GENERATION

Three sets of heat pipes, S/N 1-3, 7-9, and 13-15, were operated at 80C and used to assess the effect of wick surface area on generation rate. S/N 1-3 had no wick (zero area), S/N 7-9 had the nominal stainless-steel wick (0.0044-in-dia. wire, 81.1% porosity), and S/N 13-15 had a high-surface-area wick (0.0034-in-dia. wire, 81.2% porosity), which has 30%

more area than nominal. The average amount of gas generated and the gas-generation rates for the three sets of heat pipes are roughly the same (see Table 2.4). This result suggests that there is sufficient surface area generation even without a wick and that the rate and total gas quantity is controlled by the fluid charge, and not the available interior surface area.

3.4 MATERIALS AFFECT ON GAS GENERATION

As expected, the all-stainless-steel heat pipes had by far the least amount of gas. We also expected that the galvanic couple between stainless steel and aluminum would cause the aluminum/stainless-steel heat pipes to generate considerably more gas than the all-aluminum heat pipes. This was true only for the pipes operated at the low temperature of 40C. At 80 and 100C, the gas generation in the all-aluminum and aluminum/stainless-steel were comparable. In fact, at these temperatures the rates were higher for the all-aluminum pipes, but the amount of gas generated was less. These results suggest that the galvanic couple effectively contributes to passivation at 80C and above (hence, the lower rate of generation for the aluminum/stainless-steel combination). The lower temperature of 40C significantly retards gas generation only in the absence of the galvanic couple (hence, the relatively small quantity of gas and low rate for the all-aluminum heat pipes at the lower temperature).

3.5 THE EFFECT OF THE TYPE OF CLEANING PROCEDURE AND VACUUM FIRING FOR STAINLESS STEEL ON THE GAS GENERATION RATE

Heat pipes S/N 148-149 are identical to S/N 25-27 (both sets are all aluminum and were operated at 80C) except S/N 148-9 were chemically cleaned rather than solvent cleaned. Although S/N 148-9 were added to the test matrix (hence they had only been on test for 140 days compared to approximately 240 days for the others), the chemically cleaned pipes generated significantly less gas and at a lower rate than the solvent cleaned pipes.

Heat pipes S/N 150-151 are stainless-steel heat pipes that were also chemically cleaned rather than solvent cleaned and, in addition, the high-temperature vacuum-firing step was deleted. Heat pipes S/N 152-153 were solvent cleaned and the vacuum-firing step deleted. These pipes were operated at 80C, and thus they should be compared to S/N 34-36 which were solvent cleaned and vacuum fired. The results show that while all of these heat pipes have a low level of gas, the vacuum-firing results in the lowest level. Of the two sets that were not vacuum fired, both solvent and chemical cleaning produced comparable results.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Several new and unexpected results occurred on the program associated with the aluminum heat pipes. To explain them we hypothesize that two mechanisms occur in the heat pipes that have opposite effects on the gas generation rate. One is the chemical reaction that generates the gas and the other is passivation of the aluminum surface which retards the generation. From measurements of both the quantity of gas generated and the rate, we were led to the following tentative conclusions concerning these mechanisms.

- The presence of water, an elevated operating temperature, and a stainless-steel/aluminum galvanic couple contribute to the passivation of the aluminum surface.
- Lowering the operating temperature from 80C to 40C significantly reduces the gas-generation rate for an all-aluminum heat pipe, but not for aluminum/stainless-steel heat pipe.

Based on these conclusions, we recommend further work on aluminum/ammonia heat pipes that focuses on eliminating gas generation by promoting the passivation of the aluminum surface. The heat pipes should have water intentionally introduced during the high-temperature reflux stages of processing prior to the final charge with pure ammonia. This approach would be contrary to all past work with aluminum and ammonia; however, we feel the results of the present program sufficiently support it to ensure a reasonable probability of success.

Other results of the present program show that all-stainless-steel heat pipes generate very little gas. The vacuum-bake-out step improves the compatibility, and chemical cleaning produced somewhat better results than solvent cleaning. We feel no further work is required to improve the compatibility of ammonia and stainless steel; however, continuation of the life tests with the existing heat pipes would provide even greater confidence in their suitability for long-life spacecraft applications.

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6. Edelstein, F., Heat Pipe Manufacturing Study, prepared for NASA Goddard Space Flight Center under Contract No. NAS5-23156 by Grumman Aerospace Corporation, 1974.
7. Wanous, D. et al, 1975 IR&D Final Report, Advanced Thermal Control, TRW Document No. 99994-6314-RU-00, 1975.

APPENDIX

CONTENTS OF THE APPENDIX

Table A-1 Gas Generation Data Compilation.
SK741014 - Heat Pipe - Materials compatibility (aluminum wall).
SK741015 - Heat Pipe - Materials compatibility (stainless steel wall).
SK741001 - Tube, grooved.
SK75016 - End Cap (aluminum).
SK741024 - End Caps and fill tube (stainless steel).
SK741016 - Materials compatibility - instrumentation.
SK74020 - Evaporator block.
Manufacturing Flow Chart: Materials Compatibility Heat Pipe (304 Cres).
Manufacturing Flow Chart: Materials Compatibility (aluminum).
Assembly Cleaning Procedure PR2-28-1.
Summary of Process and Fill Procedure MSD74-3C.
Procedure for Cleaning Stainless Steel Components for Heat Pipes CRP7-12.
Procedure for Cleaning Aluminum Components for Heat Pipes CRP7-10.
Related Specification Summary
Pretest Sample Analyses
Postest Sample Analysis

Table A-1 Gas Generation Data Compilation

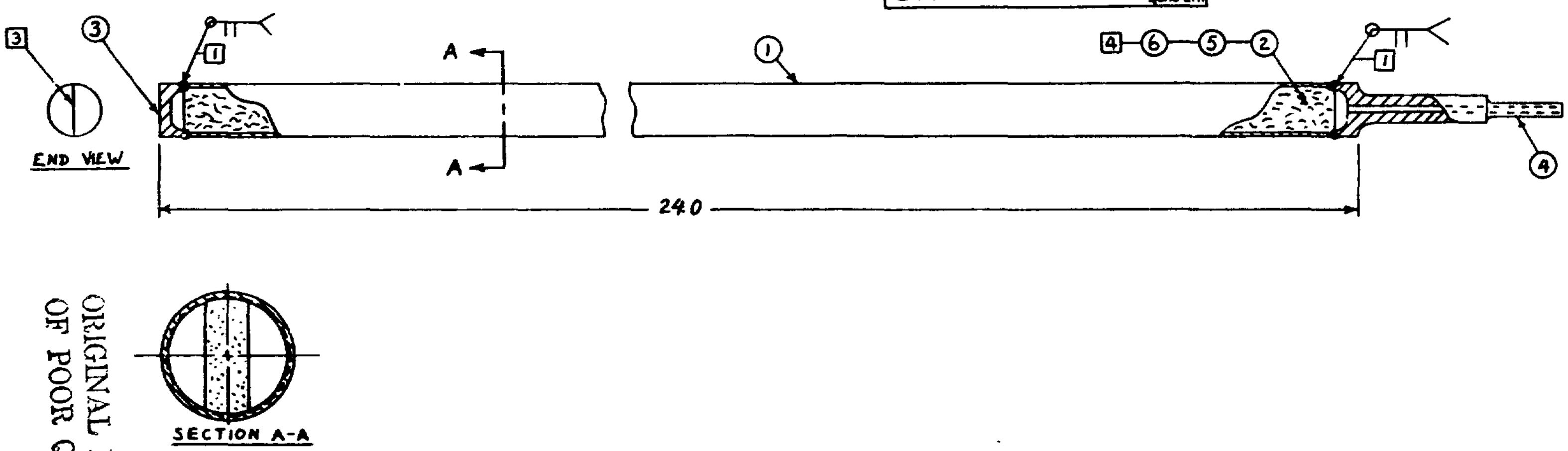
H.P. S/N	INIT. GAS MEAS. LB-MOLE	SECOND MEAS. DAYS-I.M*	SECOND MEAS. LB-MOLE	THIRD MEAS. DAYS-I.M.	THIRD MEAS. LB-MOLE	FORTH MEAS. DAYS-I.M.	FORTH MEAS. LB-MOLE	FIFTH MEAS. DAYS-I.M.	FIFTH MEAS. LB-MOLE	SIXTH MEAS. DAYS-I.M.	SIXTH MEAS. LB-MOLE	SEVENTH MEAS. DAYS-I.M.	SEVENTH MEAS. LB-MOLE	EIGHTH MEAS. DAYS-I.M.	EIGHTH MEAS. LB-MOLE	GAS-GEN. RATE AFTER 1ST MO. LB-MOLE/DAY
1	1.28×10^{-7}	38	1.19^{-7}	74	1.43^{-7}			129	1.28^{-7}	167	1.24^{-7}	209	9.80^{-8}	236	1.37^{-7}	-4.55^{-11}
2	5.96×10^{-8}	38	1.42^{-7}	74	1.57^{-7}			129	2.09^{-7}	167	2.49^{-7}	209	2.83^{-7}	236	3.20^{-7}	9.09^{-10}
3	7.05×10^{-8}	38	9.20^{-8}	74	9.95^{-8}			129	9.46^{-8}	167	1.16^{-7}	209	1.07^{-7}	236	1.20^{-7}	1.25^{-10}
4	9.91×10^{-8}	40	1.60^{-7}	76	1.89^{-7}			130	1.79^{-7}	164	2.04^{-7}	206	2.36^{-7}	236	2.34^{-7}	3.76^{-10}
5	9.49×10^{-8}	40	1.78^{-7}	76	2.19^{-7}			130	1.98^{-7}	164	2.35^{-7}	206	2.77^{-7}	236	2.72^{-7}	4.76^{-10}
6	9.93×10^{-8}	40	1.48^{-7}	76	1.76^{-7}			130	1.50^{-7}	164	1.79^{-7}	206	2.01^{07}	236	1.96^{-7}	2.37^{-10}
7	1.32×10^{-7}	38	1.60^{-7}	74	1.43^{-7}			129	1.45^{-7}	167	1.67^{-7}	209	1.87^{-7}	236	1.95^{-7}	2.24^{-10}
8	1.58×10^{-7}	38	2.28^{-7}	74	2.20^{-7}			129	2.25^{-7}	167	2.37^{-7}	209	2.84^{-7}	236	3.01^{-7}	3.86^{-10}
9	1.25×10^{-7}	38	1.56^{-7}	74	1.46^{-7}			129	1.49^{-7}	167	1.59^{-7}	209	1.84^{-7}	236	1.94^{-7}	2.13^{-10}
10	1.53×10^{-7}	26	1.94^{-7}	68	1.68^{-7}	88	1.58^{-7}	124	1.98^{-7}	155	1.74^{-7}	205	1.59^{-7}	235	2.30^{-7}	1.08^{-10}
11	1.11×10^{-7}	26	1.59^{-7}	68	1.32^{-7}	88	1.26^{-7}	124	1.65^{-7}	155	1.43^{-7}	205	1.91^{-7}	235	2.02^{-7}	2.83^{-10}
12***	1.38×10^{-7}	26	1.94^{-7}	68	1.60^{-7}	88	1.46^{-7}	124	1.97^{-7}	155	1.68^{-7}					-5.16^{-11}
13	1.06×10^{-7}	38	1.59^{-7}	74	1.46^{-7}			129	1.52^{-7}	167	1.74^{-7}	209	2.07^{-7}	236	2.11^{-7}	3.19^{-10}
14****	1.51×10^{-8}	38	3.61^{-8}	74	1.97^{-8}			129	5.99^{-8}	167	1.10^{-7}	209	1.26^{-7}	236	1.38^{-7}	
15	9.88×10^{-8}	38	1.40^{-7}	74	1.24^{-7}			129	1.21^{-7}	167	1.39^{-7}	209	1.58^{-7}	236	1.64^{-7}	1.61^{-10}
18**	1.53×10^{-7}	33	1.88^{-7}	71	2.25^{-7}	90	2.12^{-7}	125	2.15^{-7}	161	2.20^{-7}	205	2.77^{-7}	231	2.80^{-7}	4.29^{-10}
19	-3.63×10^{-10}	33	1.91^{-8}	71	1.14^{-8}	90	1.30^{-8}	125	1.34^{-8}	161	1.12^{-8}	205	2.25^{-8}	231	2.02^{-8}	2.20^{-11}
20	1.09×10^{-8}	33	7.64^{-7}	71	8.84^{-7}	90	6.93^{-7}	125	6.83^{-7}	161	7.19^{-7}	205	8.73^{-7}	231	7.79^{-7}	1.41^{-10}
21	-6.24×10^{-9}	33	5.83^{-7}	71	6.97^{-7}	90	5.26^{-7}	125	5.37^{-7}	161	5.72^{-7}	205	6.68^{-7}	231	5.93^{-7}	8.78^{-11}
22	6.78×10^{-9}	40	3.57^{-8}	76	4.66^{-8}			130	4.62^{-8}	164	5.98^{-8}	206	6.22^{-8}	23[illegible]	5.74^{-8}	1.21^{-10}
23	2.09×10^{-8}	40	5.25^{-8}	76	5.97^{-8}			130	5.92^{-8}	164	6.99^{-8}	206	7.39^{-8}	236	7.49^{-8}	1.17^{-10}
24	1.93×10^{-8}	40	4.00^{-8}	76	4.05^{-8}			130	5.42^{-8}	164	6.08^{-8}	206	6.68^{-8}	236	6.59^{-8}	1.54^{-10}
25	1.50×10^{-8}	38	8.42^{-8}	74	1.26^{-7}			129	1.51^{-7}	167	1.57^{-7}	209	1.76^{-7}	241	2.24^{-7}	5.80^{-10}
26	1.43×10^{-8}	38	9.70^{08}	74	1.09^{-7}			129	1.29^{-7}	167	1.34^{-7}	209	1.43^{-7}	241	1.79^{-7}	3.50^{-10}
27	1.81×10^{-8}	38	8.31^{-8}	74	9.28^{-8}			129	1.53^{-7}	167	1.55^{-7}	209	1.68^{-7}	214	2.16^{-7}	6.13^{-10}
28	2.36×10^{-8}	26	7.93^{-8}	68	1.19^{-7}	88	9.92^{-8}	124	1.38^{-7}	155	1.22^{-7}	205	1.35^{-7}	235	1.48^{-7}	2.72^{-10}
29	1.68×10^{-8}	26	6.72^{-8}	68	8.99^{-8}	88	7.96^{-8}	124	1.09^{-7}	155	1.05^{-7}	205	1.32^{-7}	235	1.58^{-7}	4.01^{-10}
30	2.83×10^{-8}	26	6.50^{-8}	68	1.16^{-7}	88	1.01^{-7}	124	1.42^{-7}	155	1.25^{-7}	205	1.40^{-7}	235	1.59^{-7}	3.67^{-10}
31	8.17×10^{-9}	40	6.00^{-9}	76	7.73^{-9}			130	6.17^{-9}	164	7.35^{-9}	206	6.66^{-9}	236	6.97^{-9}	1.[illegible]$^{-12}$
32	-3.17×10^{-10}	40	8.15^{-10}	76	-3.54^{-10}			130	-1.64^{-9}	164	-6.84^{-10}	206	-1.03^{-9}	236	3.64^{-10}	-3.07^{-12}
33	1.51×10^{-10}	40	-1.10^{-9}	76	5.92^{-10}			130	-1.18^{-9}	164	-6.50^{-10}	206	-1.27^{-9}	236	1.02^{-9}	2.86^{-12}
34	-1.72×10^{-10}	33	-4.14^{-10}	71	-4.52^{-10}			125	5.20^{-10}	161	-5.66^{-10}	205	7.06^{-10}	231	1.47^{-9}	3.48^{-12}
35	4.03×10^{-9}	33	4.86^{-12}	71	1.14^{-9}			125	3.72^{-9}	161	6.51^{-9}	205	1.14^{-8}	231	1.25^{-8}	6.69^{-11}
36	-6.73×10^{-10}	33	-2.16^{-10}	71	-1.60^{-9}			125	1.40^{-9}	161	2.65^{-9}	205	6.24^{-9}	231	1.04^{-8}	5.33^{-11}
37	1.60×10^{-9}	26	4.54^{-9}	68	1.10^{-9}	88	1.35^{-9}	124	2.89^{-8}	155	2.98^{-8}	205	3.12^{-8}	235	3.60^{-8}	6.01^{-11}
38	6.02×10^{-9}	26	8.05^{-9}	68	6.75^{-9}	88	7.24^{-9}	124	7.98^{-9}	155	9.11^{-9}	205	1.15^{-8}	235	1.28^{-8}	2.69^{-11}
39	3.10×10^{-9}	26	2.52^{-9}	68	3.26^{-9}	88	6.70^{-9}	124	-1.65^{-9}	155	1.69^{-10}	205	5.18^{-9}	235	8.32^{-9}	1.67^{-11}
148	2.89×10^{-8}	35	5.43^{-8}	71	7.02^{-8}	115	1.01^{-7}	140	8.74^{-8}							3.83^{-10}
149	2.22×10^{-8}	36	6.49^{-8}	77	7.91^{-8}	117	8.17^{-8}	147	9.12^{-8}							2.18^{-10}
150	7.70×10^{-9}	36	7.54^{-9}	77	1.42^{-8}	117	1.42^{-8}	147	1.93^{-8}							9.40^{-11}
151	5.12×10^{-9}	36	7.12^{-9}	77	1.52^{-8}	117	1.37^{-8}	147	1.15^{-8}							3.45^{-11}
152	6.72×10^{-9}	35	1.01^{-8}	71	1.49^{-8}	115	1.52^{-8}	140	1.85^{-8}							6.94^{-11}
153	6.47×10^{-9}	35	1.76^{-8}	71	2.08^{-8}	115	2.33^{-8}	140	2.44^{-8}							6.42^{-11}

* Numbers of days from initial measurement.

** Heat pipe 17 ruptured and 16 was damaged during processing.

*** Heat pipe number 12 leaked after the sixth measurement.

****Average rate not calculated because data could not be fit with straight line.



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NOTES:

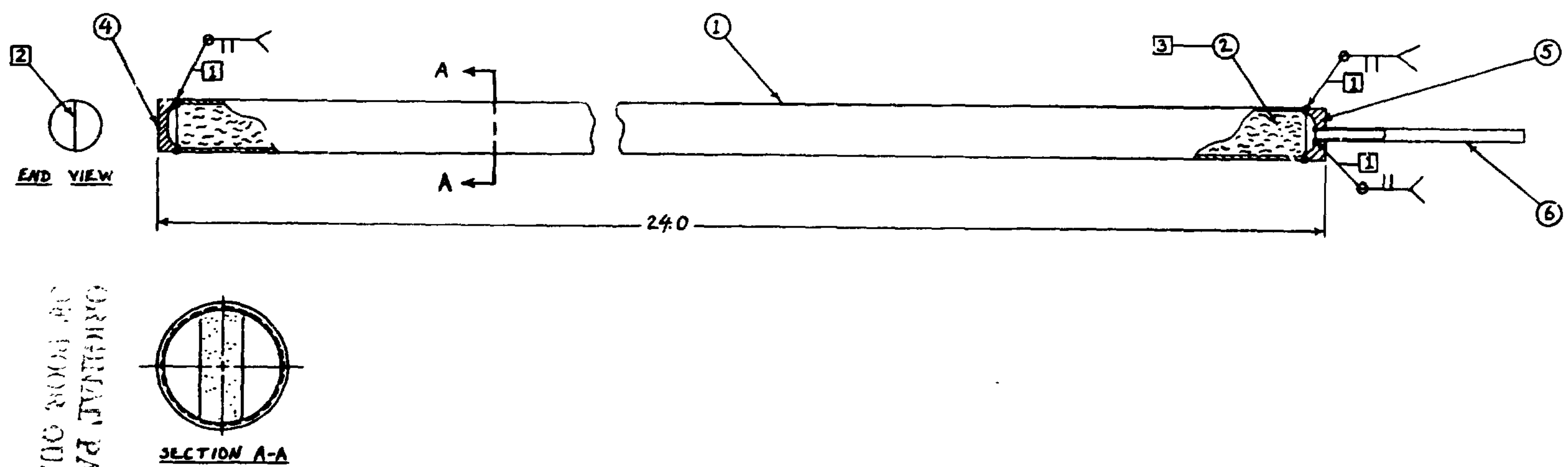
1. TIG WELD PER PR3-1.
2. SK741014-1 HAS NO WICK.
   SK 741014-2 USES ITEM 2 WICK.
   SK 741014-3 USES ITEM 5 WICK.
   SK 741014-4 USES ITEM 6 WICK.
3. SCRIBE END CAP PRIOR TO ASSEMBLY AS SHOWN. ALIGN MARK ON END CAP WITH WICK POSITION.
4. TRIM WICK FLUSH WITH ENDS OF TUBE AS SHOWN.

ITEM	PART NO.	QTY	DESCRIPTION	MATERIAL	SPEC.
6	SK1003-1	1	WICK 21% DENSITY, 0.005 WIRE	AL ALLOY 5056	
5	SK1003-3	1	WICK 24% DENSITY, 0.0036 WIRE	304 CRES	
4	SK75076-2	1	END CAP 1/2 DIA. ROD	AL ALLOY 6061-T6	
3	SK75076-1	1	END CAP 1/2 DIA. ROD	AL ALLOY 6061-T6	
2	SK1003-2	1	WICK 21% DENSITY, 0.005 WIRE	304 CRES	
1	SK741001-2A	1	TUBE 1/2 O.D. X .035 WALL	AL ALLOY 6061-T6	

PARTS LIST

ORIGINATOR	DATE	TITLE	
G FLEISCHMAN	10/15/74	HEAT PIPE MATERIALS COMPATIBILITY	ENGINEERING SKETCH TRW
MJO			SK 741014 SHEET OF

SK



NOTES:

1. TIG WELD PER PR3-1.
2. SCRIBE END CAP PRIOR TO ASSEMBLY AS SHOWN. ALIGN MARK ON END CAP WITH WICK POSITION
3. TRIM WICK FLUSH WITH ENDS OF TUBE AS SHOWN.

ITEM	PART NO.	QTY	DESCRIPTION	MATERIAL	SPEC.
6	SK741024-3	1	FILL TUBE 1/8 O.D. X 0.020 WALL	304 CRES	
5	SK741024-2	1	END CAP 1/2 DIA. ROD	304 CRES	
4	SK741024-1	1	END CAP 1/2 DIA ROD	304 CRES	
3	SK1003-3	1	WICK 24% DENSITY 0.0036 WIRE	304 CRES	
2	SK1003-2	1	WICK 21% DENSITY 0.005 WIRE	304 CRES	
1	SK741001-2B	1	TUBE 1/2 O.D X 0.035 WALL	304 CRES	

PARTS LIST

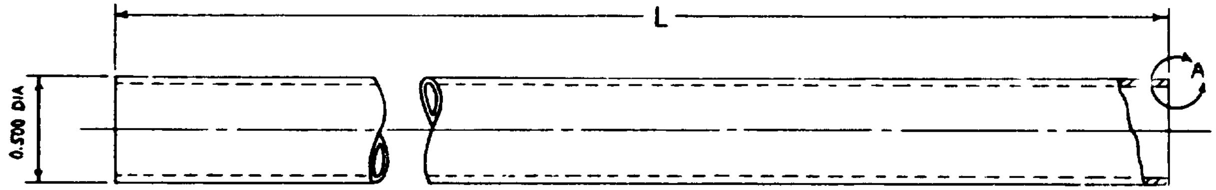
ORIGINATOR	DATE	TITLE	
G FLEISCHMAN	10/15/74	HEAT PIPE MATERIALS COMPATIBILITY	ENGINEERING SKETCH TRW
MJO			SK 741015 SHEET OF

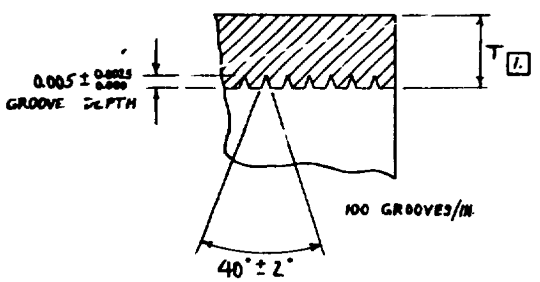
SK 741001

NOTES:

1. [L] SELECT TUBES FOR NOMINAL I.D. $^{+.005}_{-.000}$ DIMENSION.
2. INTERNAL GROOVE ENTIRE LENGTH PER SP-13B-02.

DASH NO.	L	T (STK.)
-1	35.75	0.035
-2	23.55	0.035
-3	35.88	0.035
-4	70.86	0.035
-5	38.58	0.028
-6	70.00	0.035
-7	6.60	0.035
-8	52.00	0.035





DETAIL A (20~1)

LETTER	MATERIAL	SPEC
C	PH15-7Mo S.S.	
B	304 CRES	AMS5560
A	6061-T6 AL	WW-T-700

ORIGINATOR	DATE	TITLE	
G. FLEISCHMAN	10-1-74	TUBE, GROOVED - HEAT PIPE	ENGINEERING SKETCH
MJO			SK 741001
			SHEET OF

SK 75016	REVISIONS			
	LTR	DESCRIPTION	DATE	APPROVED

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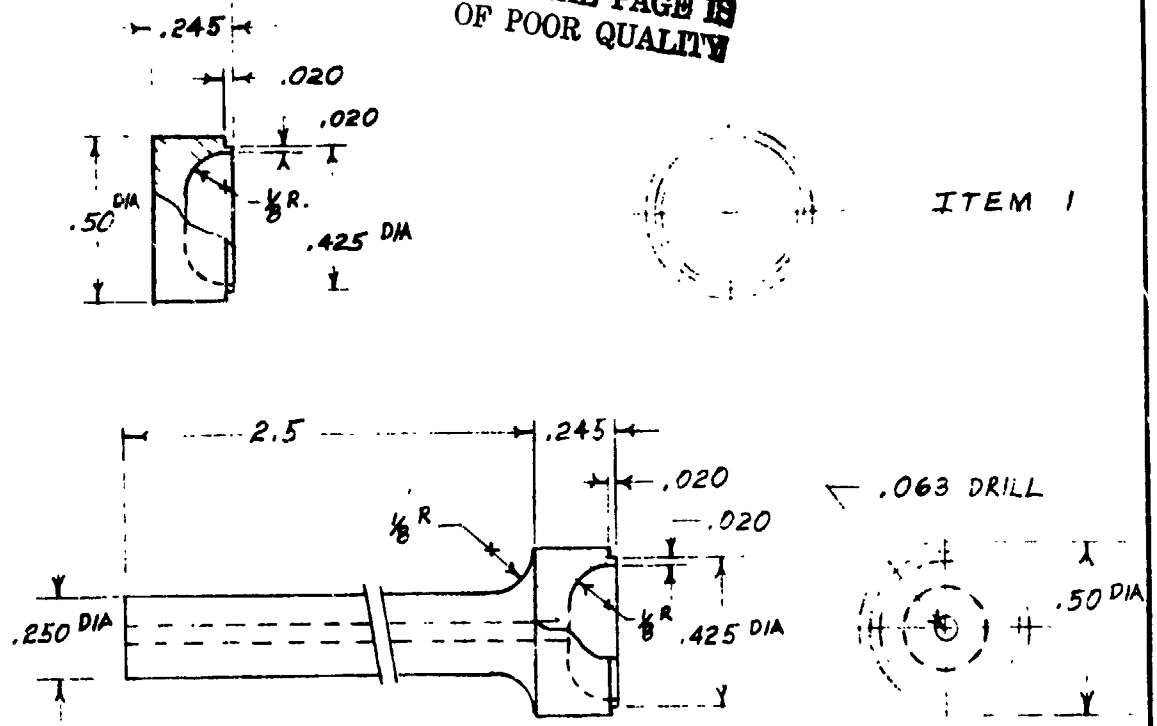


ITEM 2

NOTES:

1. ITEM 2 HEAT (ANNEAL) AT 800 ±25 °F FOR 2 HOUR IN INERT GAS ATMOSPHERE. TO BE PERFORMED BY REQUESTOR.

SK 75016-2	END CAP	6061-T6 AL ALLOY ROD, .5 DIA	2
SK 75016-1	END CAP	6061-T6 AL ALLOY ROD, .5 DIA	1
PART NO.	DESCRIPTION	MATERIAL	ITEM NO.

ENGINEERING SKETCH

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

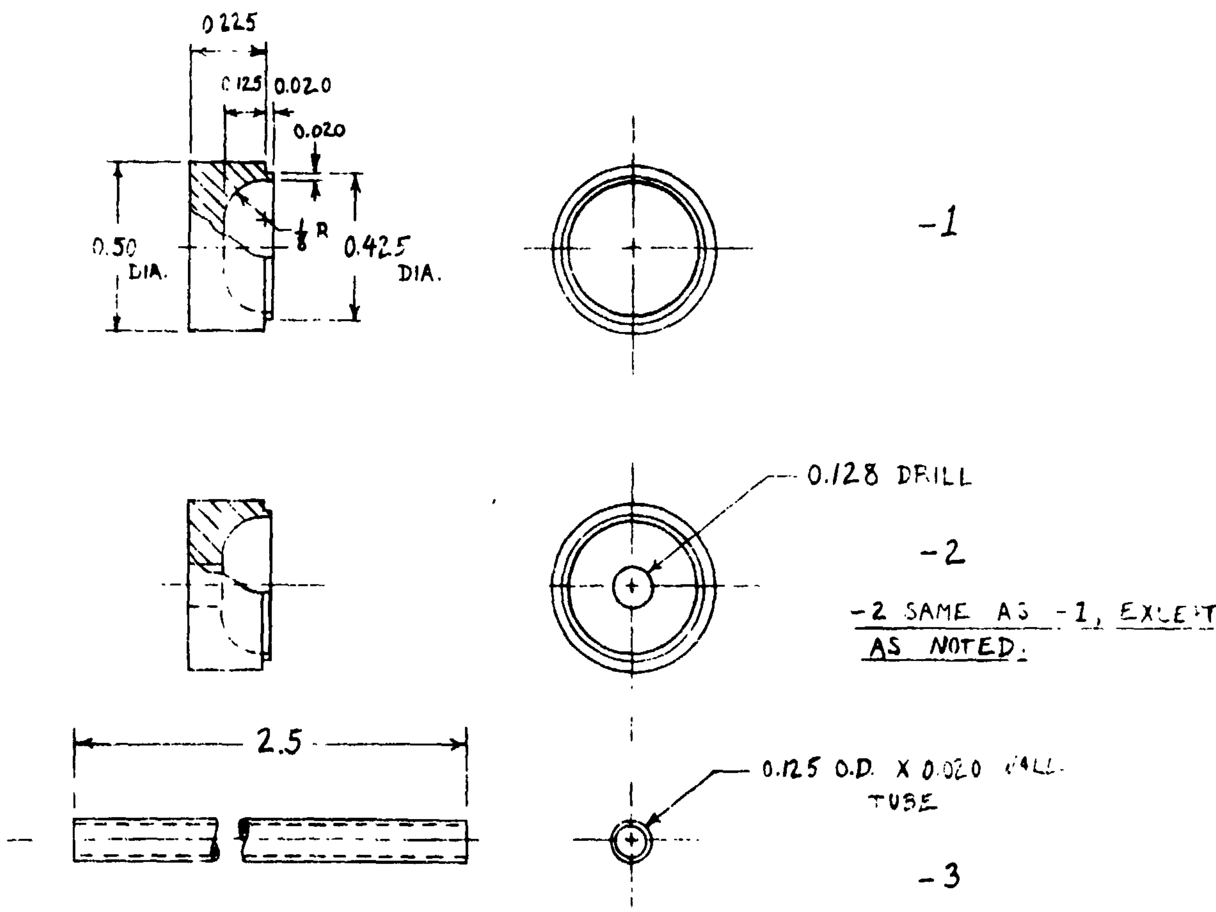
ORIGINATOR	DATE
V. REINEKING	4-21-75
MJO	

END CAP

SIZE	CODE IDENT NO.	
A	11982	SK 75016
SCALE 2~1		SHEET 1 OF 1

SYSTEMS 523 REV. 12-71

SK	REVISIONS			
	LTR	DESCRIPTION	DATE	APPROVED



SK741024-3	FILL TUBE	304 TUBE, 0.125 O.D. X 0.020 WALL
SK741024-2	END CAP	304 CRES ROD, 0.500 DIA.
SK741024-1	END CAP	304 CRES ROD, 0.500 DIA.
PART NO.	DESCRIPTION	MATERIAL

ENGINEERING SKETCH

TRW SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

ORIGINATOR: G. FLEISCHMAN
DATE: 10/24/74

END CAPS AND FILL TUBE

MJO

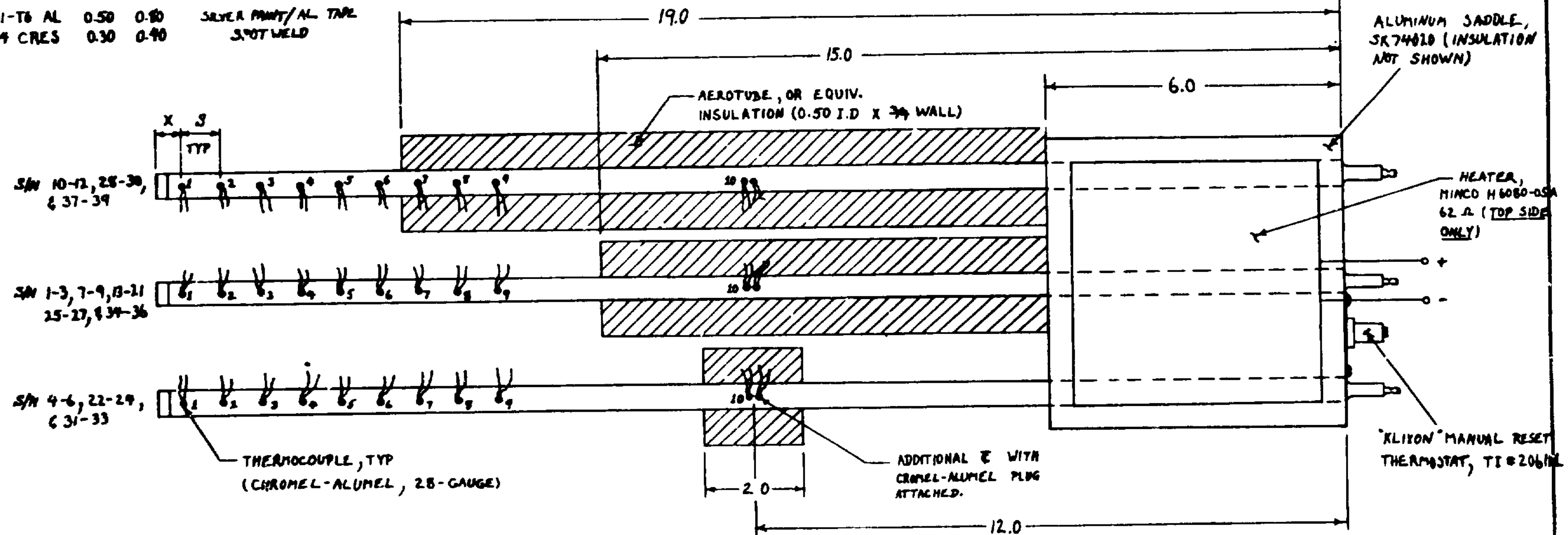
SIZE	CODE IDENT NO.	
A	11982	SK 741024

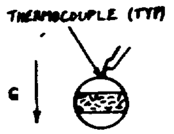
SCALE 2~1 | SHEET 1 OF

SYSTEMS 523 REV. 12-71

SK

MATERIAL	X (IN.)	S (IN)	THERMOCOUPLE ATTACHMENT
6061-T6 AL	0.50	0.80	SILVER PAINT/AL TAPE
304 CRES	0.30	0.40	SPOT WELD





WICK ORIENTATION

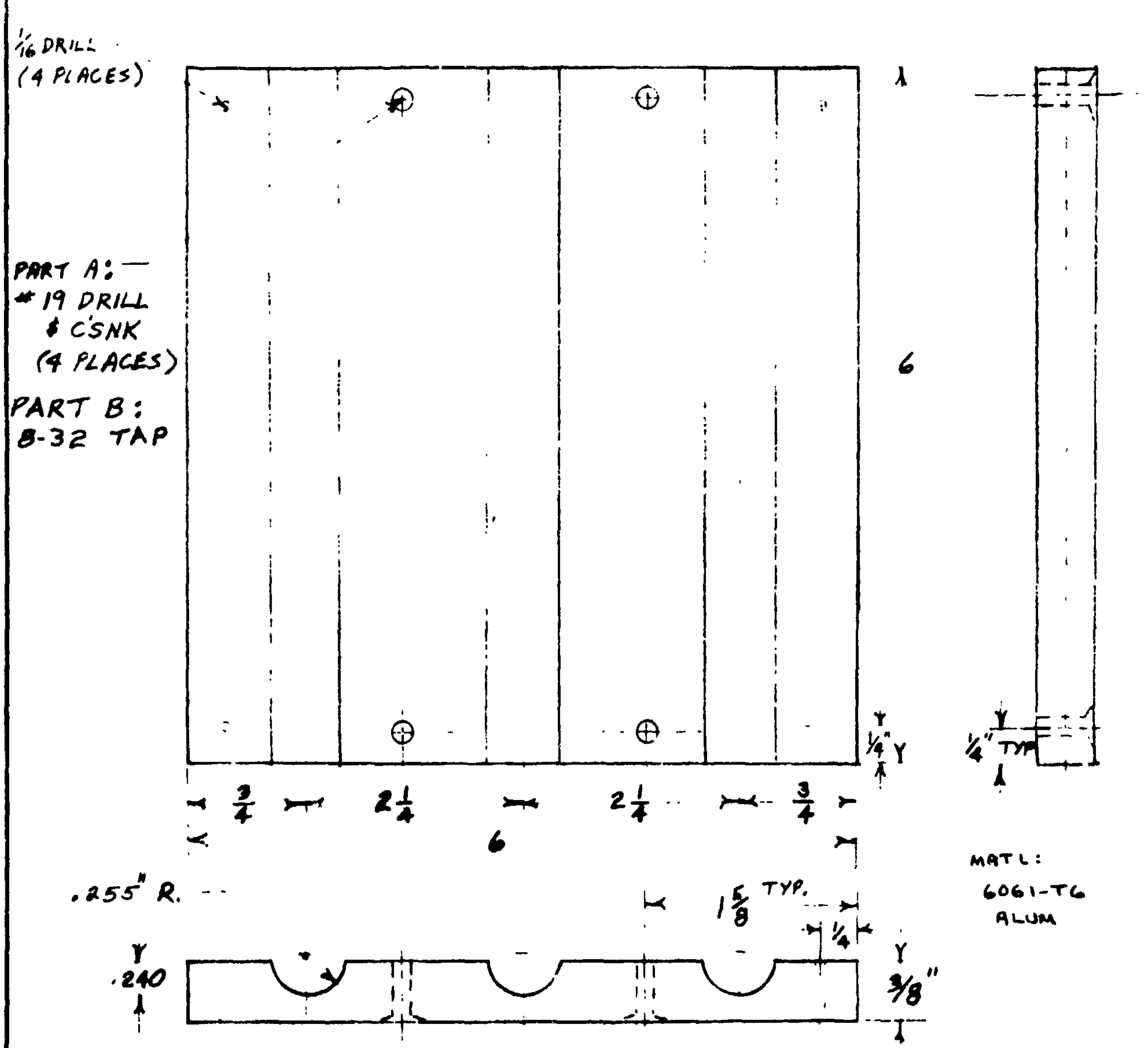
NOTES:

1. HEATER BONDED TO TOP SADDLE BLOCK ONLY WITH MINCO #6 ADHESIVE.
2. PLACE SOFT ALUMINUM FOIL (0.001 THK) AND SILICONE GREASE (DC-200 OR EQUIV) BETWEEN HEAT PIPES AND SADDLE BLOCK.

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
G. FLEISCHMAN	12/20/74	MATERIALS COMPATIBILITY INSTRUMENTATION	TRW
MJO			SK 741016
			SHEET OF

SK 74020

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



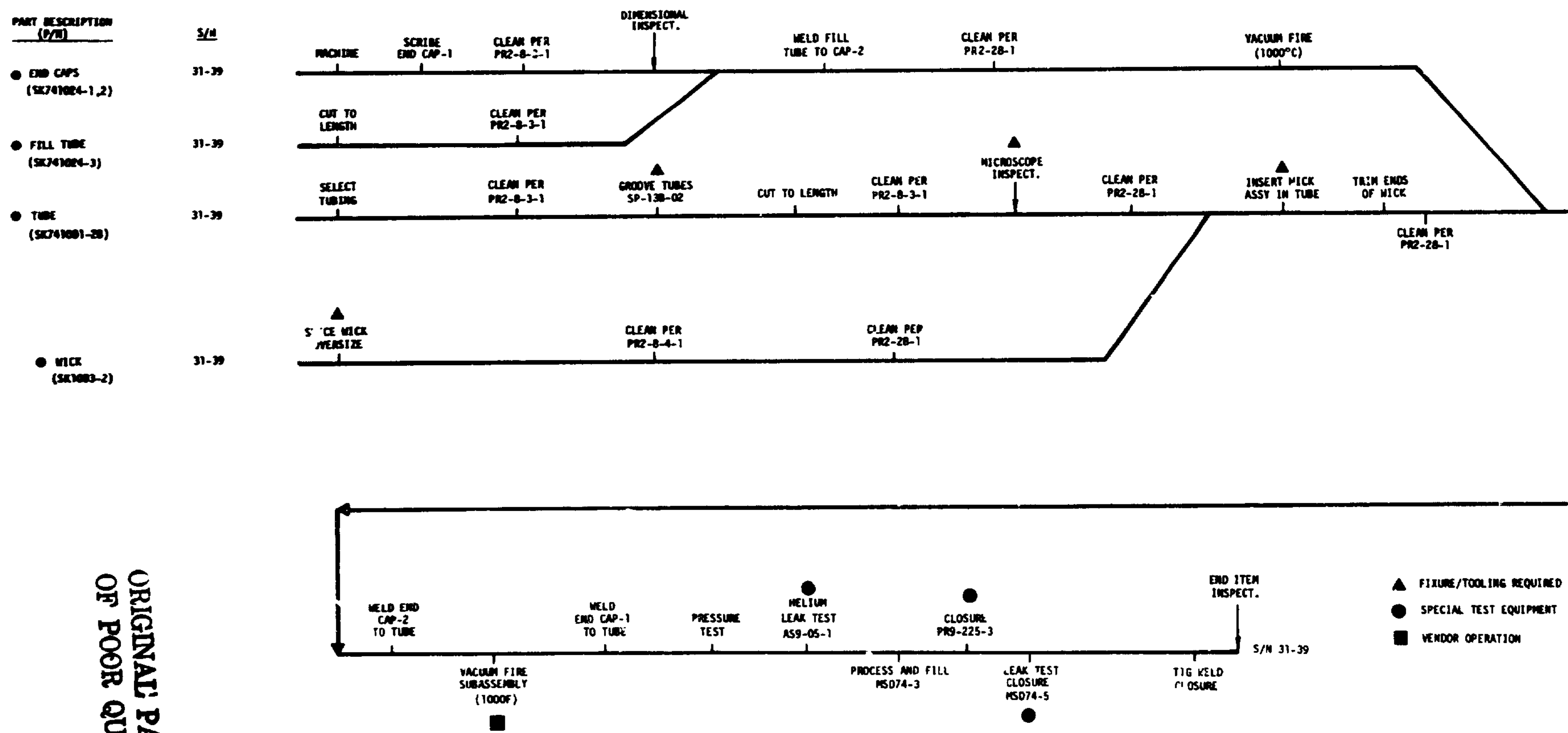
PART A – DRILL & C'SNK FOR 8-32 FLATHEAD SCREW
PART B – DRILL AND 8-32 TAP.

MATCH MACHINE AND DRILL EACH SET

ENGINEERING SKETCH	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
ORIGINATOR: V. Reinking — DATE: 11/4/74	EVAPORATOR BLOCK
MJO	SIZE: A — CODE IDENT NO.: 11982 — SK 74020
	SCALE — SHEET 1 OF 1

SYSTEMS 523 REV. 12-71

MANUFACTURING FLOW CHART: MATERIALS COMPATIBILITY HEAT PIPE (304 CRES)
(SK741015)



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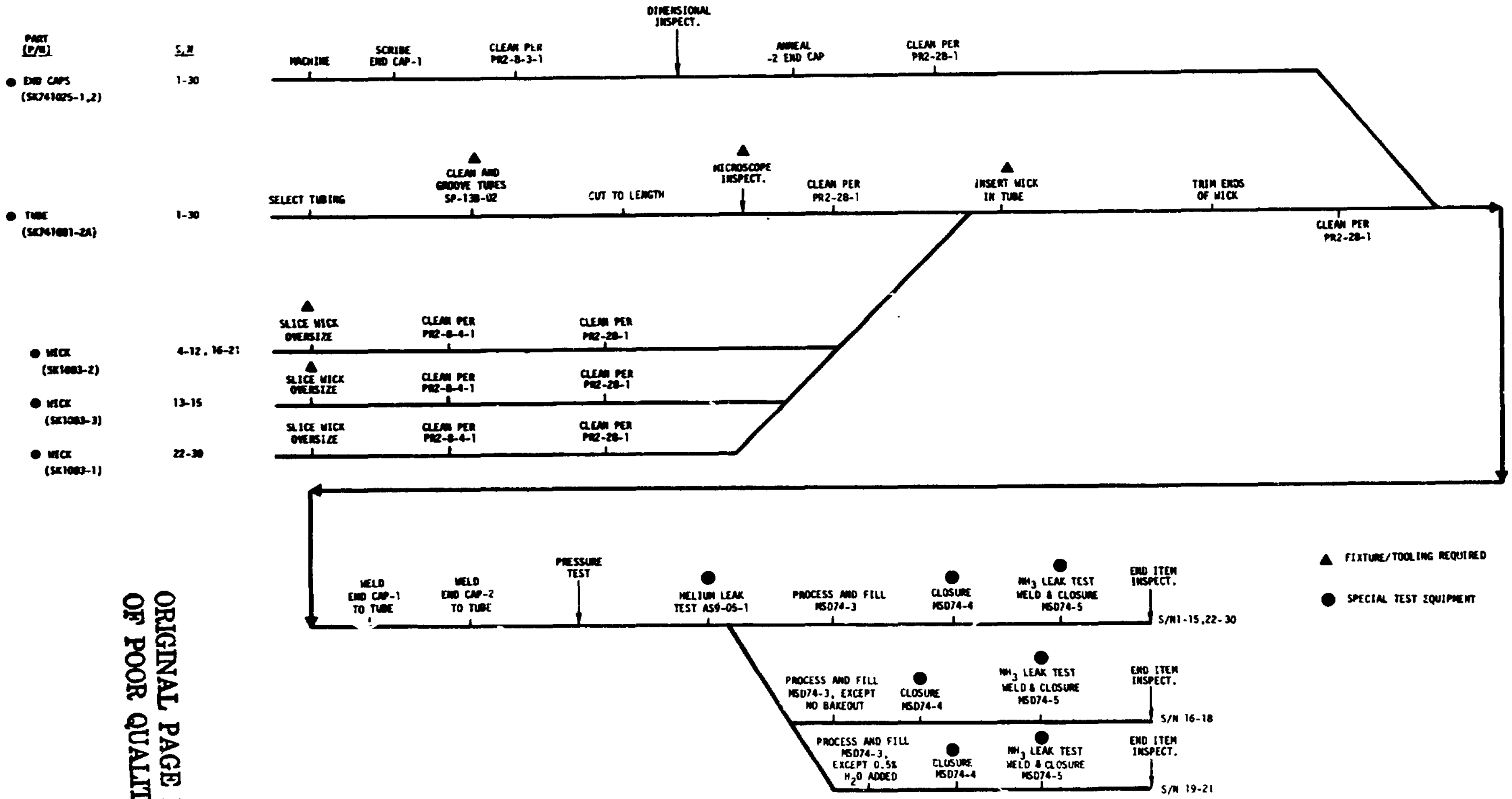
MANUFACTURING FLOW CHART. MATERIALS COMPATIBILITY HEAT PIPE (ALUMINUM)
(SK741014)



ASSEMBLY CLEANING PROCEDURE

PR2-22-1

USE FILTERED SOLVENTS
PR13-6-1

ULTRASONIC CLEAN IN FREON TF,
MINIMUM OF 15 MINUTES

DRY IN VACUUM OVEN AT 212 $\pm$ 20°F
FOR MINIMUM OF 5 MINUTES

ULTRSONIC CLEAN IN ACETONE,
MINIMUM OF 15 MINUTES

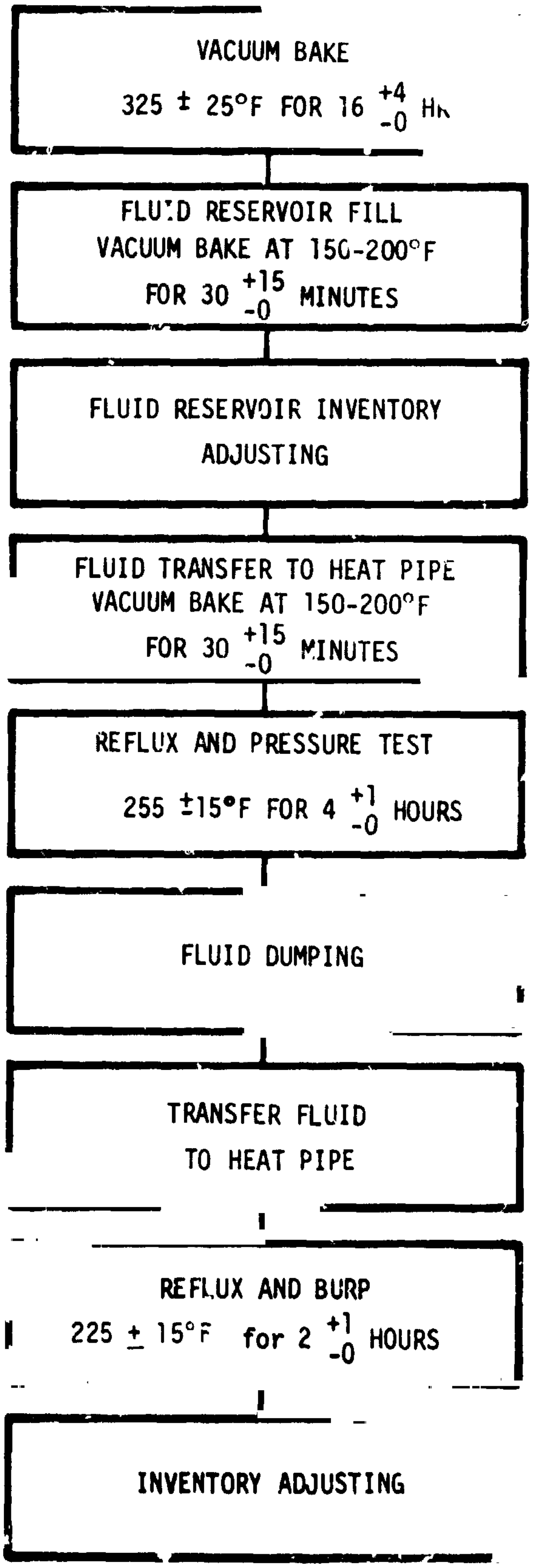
DRY IN VACUUM OVEN AT 212 $\pm$ 20°F
FOR MINIMUM OF 5 MINUTES

ULTRASONIC CLEAN IN HEXANE,
MINIMUM OF 15 MINUTES

DRY IN VACUUM OVEN AT 212 $\pm$ 20°F
FOR MINIMUM OF 5 MINUTES

STORE IN SUITABLE CONTAINER

FIGURE 1.



Summary of Process and Fill Procedure MSD74-3C

PROCEDURE FOR CLEANING STAINLESS STEEL COMPONENTS FOR HEAT PIPES

CRP 7-12

1. Ultra-sonically clean in FREON PCA (TF) for 10-15 minutes. Hold in vapor phase for 3-5 minutes.

2. Blow dry with heated nitrogen (120-150°).

3. Ultra-sonically clean in TURCO 4215 for 10-15 minutes.

4. Rinse in deionized water until PH is equal to system water. Use ultra-sonic energy.

   CAUTION: Parts must not remain wet with water for more than 4 hours. If cleaning is interrupted for any reason, complete drying cycle.

5. Immerse in chromated de-oxide 8-10 minutes. Use ultra-sonic.

6. Rinse in de-ionized water per Step 4.

7. Passivate per PR 2-9, use ultrasonic energy. Solution 4 in Table II.

8a. Rinse in de-ionized water per Step 4.

8b. Immerse in chromated de-oxide 8-10 minutes. Use ultra-sonic energy.

9. Rinse in de-ionized water per Step 4.

10. Blow off excess water with heated 120-150°F GN_2.

11. Rinse in isopropyl alcohol 5 minutes. Use ultra-sonic energy.

12. Blow off excess alcohol with heated nitrogen (120-150°F).

13. Vacuum dry 180°F for 2 hours. Back fill with GN_2.

14. Package each component individually per PR 2-2.

REVISED: 9-26-75

PROCEDURE FOR CLEANING ALUMINUM COMPONENTS FOR HEAT PIPES

CRP7-10

1. Ultra-sonically clean in FREON PCA (TF) for 10 to 15 minutes. Hold in vapor phase for 3 to 5 minutes.

2. Blow dry with heated 120°F to 150°F nitrogen.

3. Ultra-sonically clean in TURCO 4215 for 10 to 15 minutes.

4. Rinse in deionized water until pH equals system water. Use ultra-sonic energy.

   CAUTION: Parts must not remain wet with water for more than 5 hours. If cleaning is interrupted for any reason, complete drying cycle.

5. Immerse in chromated deoxidizer 8 to 10 minutes. Use ultra-sonic energy.

6. Rinse in deionized water per Step 4.

7. Blow off excess water with heated 120°F - 150°F GN_2.

8. Rinse in isopropyl alcohol 5 minutes. Use ultra-sonic energy.

9. Blow off excess alcohol with heated nitrogen (120°F - 150°F).

10. Vacuum dry 180°F for 2 hours. Back fill with GN_2.

11. Package each component individually per PR 2-2.

REVISED: 6-16-75

Related Specification Summary

Additional TRW Specifications are referred to at various places in the body of the report. Since the inclusion of these specifications in their entirety would not add significantly to the report, their key aspects will be abstracted for completeness.

SPECIFICATION	SCOPE
PR 2-2 R	This specification establishes the minimum requirements and procedures for cleaning and protective closure of all metallic and non-metallic lines, fittings, and detail parts of regulators, valves, or other components through which liquid or gaseous fluid will be carried.
PR 2-8 C	This specification establishes the requirements and procedures for solvent cleaning of detail parts, assemblies, and components.
PR 2-9 F	This specification establishes the procedures and materials to be used for cleaning, descaling and passivation of the following corrosion and heat resistant alloys: AISI 300 series, etc.
PR 13-6-1	This specification establishes the procedures to be used in the preparation of controlled contaminant fluid levels for cleaning heat pipes and heat pipe hardware.

WEST COAST TECHNICAL SERVICE INC / 17605 FABRICA WAY, SUITE D / CERRITOS, CA 90701

REPORT

(213) 921-9831
(714) 523-9200

date/ March 18, 1975 **job no./** 7763

p.o. no./ A21993CJ5E MJO #255391

prepared for/ TRW Systems
One Space Park
Redondo Beach, California 90278

Mr. W.T. Anderson

The samples submitted by you have been received in our laboratory and analyzed. The results of these analyses are as follows:

	Parts Per Million 20.80 g (150 psi) Ammonia Gas	 Liquid
Hydrogen	1.9	less than 10 ppm*
Water	less than 10 ppm*	less than 10 ppm*
Nitrogen	0.1	less than 10 ppm*
Oxygen	less than 0.1 ppm*	less than 10 ppm*
Argon	less than 0.1 ppm*	less than 10 ppm*
Carbon Dioxide	less than 10 ppm*	less than 10 ppm*
Ammonia	balance	balance

* Limit of detection

If we can be of any further service, please do not heistate to contact us.

Respectfully submitted,

WEST COAST TECHNICAL SERVICE INC.

DJ Worthington for

H. Dwight Fisher, Ph.D.
Vice President-Technical Director

HDF/kd

Report

Prepared For

Mr. Ed Luedke
TRW Systems
One Space Park
Redondo Beach, California 90278

Date	Job No
February 3, 1976	9610

PO No

A78036CB6E

WEST COAST TECHNICAL SERVICE INC.

17605 Fabrica Way, Suite D
Cerritos, California 90701
213/921-9831
714/523-9200

The ammonia samples received 1-16-76 have been analyzed by mass spectrometry for the following components:

	Parts Per Million		
	Gas S/N 8	Gas S/N 27	Liquid S/N 27
Hydrogen	10249	7755	less than 10 ppm*
Water	less than 10 ppm*	less than 10 ppm*	less than 10 ppm*
Nitrogen	485	488	less than 10 ppm*
Oxygen	less than 1 ppm*	1	less than 10 ppm*
Argon	6	6	less than 10 ppm*
Carbon Dioxide	less than 10 ppm*	less than 10 ppm*	less than 10 ppm*
Helium (Mole Percent)	16.982	20.560	less than 10 ppm*
Ammonia (Mole Percent)	81.944	78.615	Balance

*limit of detection

If we can be of any further assistance, please do not hesitate to contact us.

Respectfully submitted,

WEST COAST TECHNICAL SERVICE, INC.

H. Dwight Fisher, Ph.D.
Vice President-Technical Director

HDF/cl